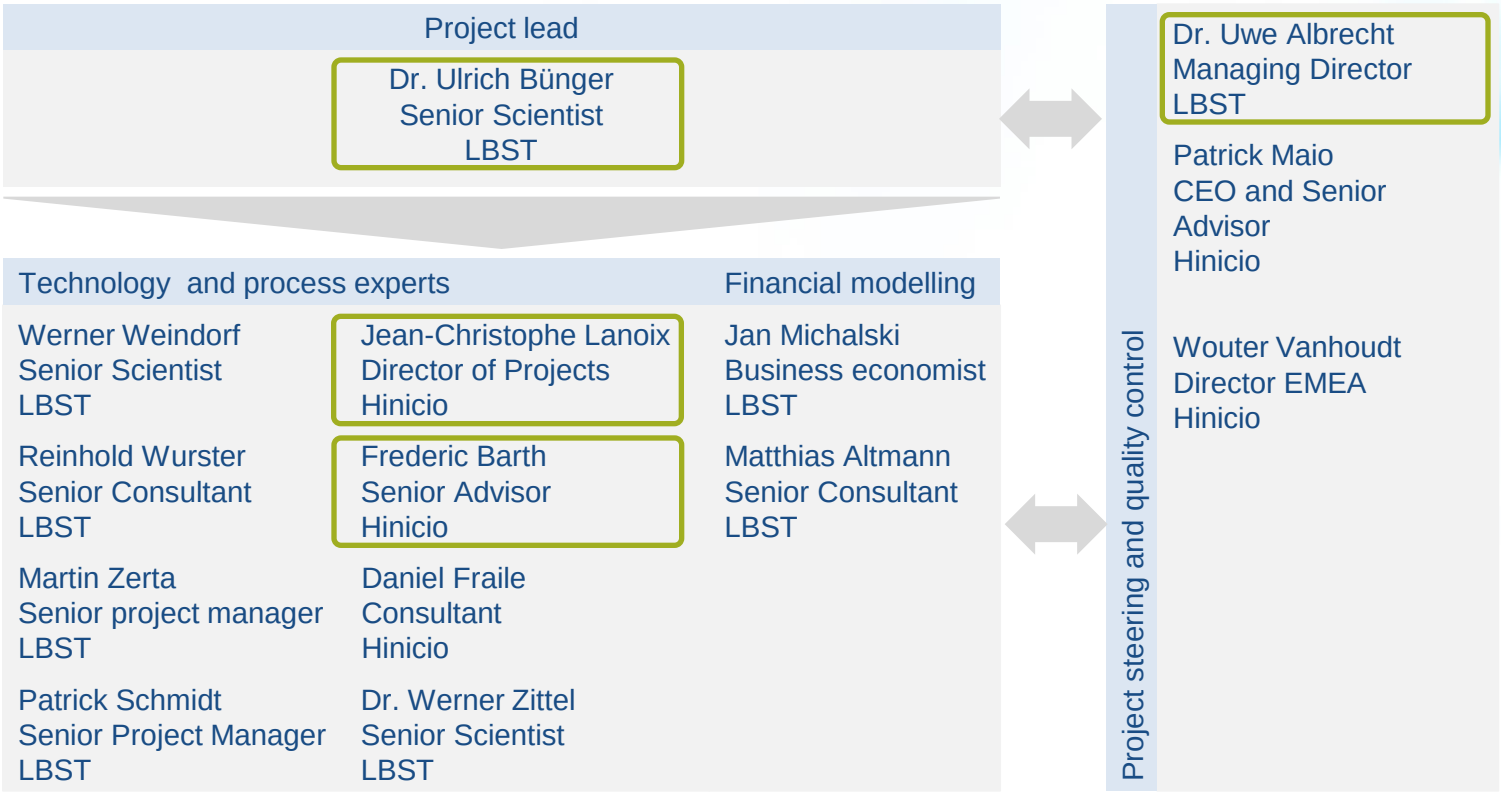
Programme Review Days 2015

Green Hydrogen Pathways Study

Ulrich Bünger – Ludwig-Bölkow-Systemtechnik
Frédéric Barth - Hinicio

PROJECT TEAM



Ludwig-Bölkow-Systemtechnik GmbH
Daimlerstr. 15
85521 Ottobrunn, Germany
Web: http://www.lbst.de

Contact: +49 89 608110-42
ulrich.buenger@lbst.de

Hinicio
Rue des Palais, 44
1030 Brussels, Belgium
Web: http://www.hinicio.com

Contact: +32 22 11 34 11
wouter.vanhoudt@hinicio.com

STATUS AND STUDY GOAL

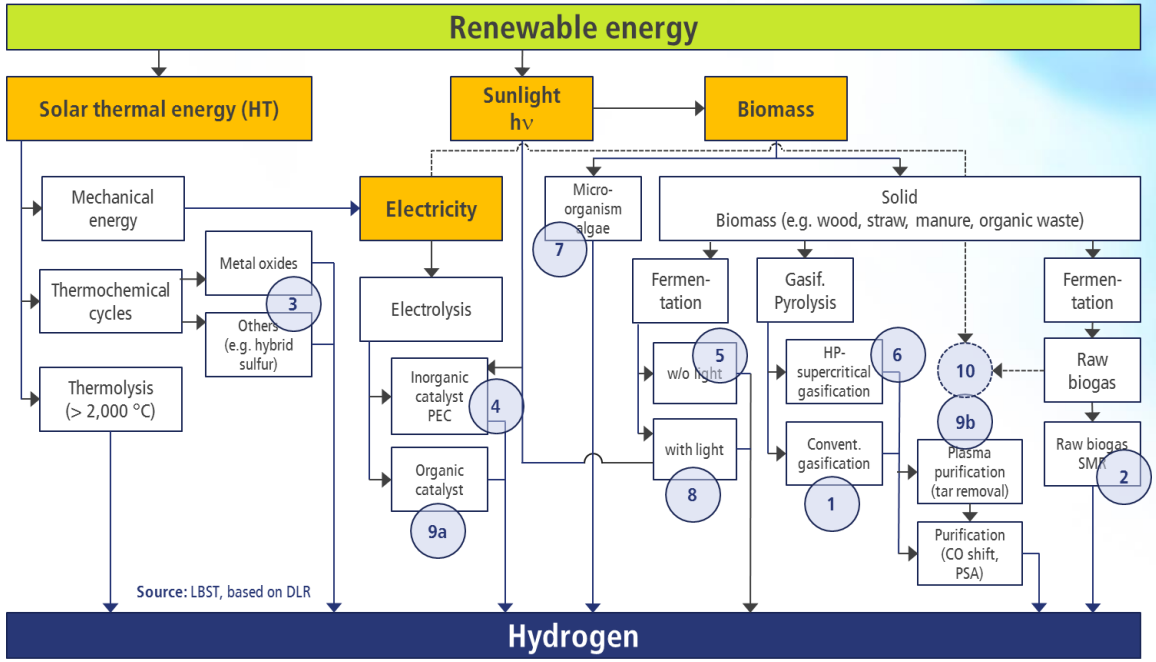
- Status
  - Hydrogen (H_2) produced from fossil sources by SMR
  - Renewable ‘green’ hydrogen produced by WEL
- Study goal
  - Identify most promising green H_2 production pathways other than electrolysis
  - Propose topic content for upcoming FCH 2 JU calls

SMR: Steam Methane Reforming WEL: Water Electrolysis

ORIGINALLY PROPOSED PATHWAYS

11 Green H_2 Pathways pre-assessed

- Feedstock
- Technology
- TRL (1-9)
- Applicability
  Local/(semi)-central



TRL: Technology Readiness Level

Approach & Methodology

Research / review of 11 pathways

- Literature
- Publications
- Patents

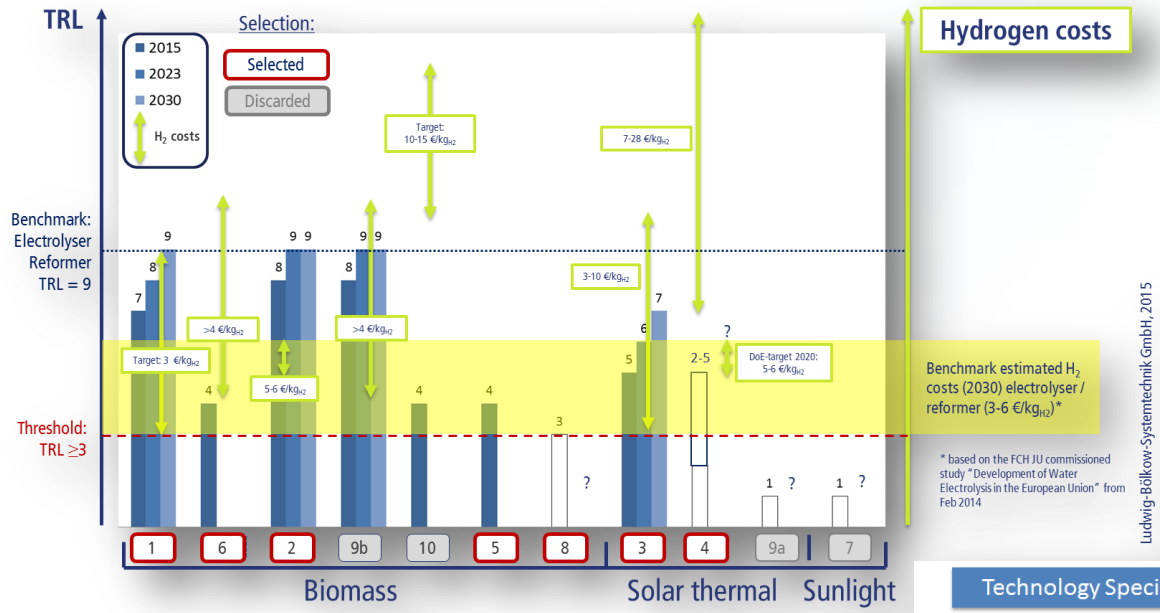
Bibliometric analysis

- EU positioning
- Stakeholder interviews
- KPI analysis: H_2 costs, footprint, lifetime, feedstock availability, environment

BIOMASS	1	Biomass gasification or pyrolysis
	6	Supercritical water gasification of biomass
	2	Raw biogas reforming
	9b	Plasma-supported gasification
	10	Plasma-based carbon black process
	5	Fermentation (biological H_2 production, dark fermentation)
	8	Photofermentation (biological H_2 production)
SOLAR THERMAL	3	Thermochemical water splitting (thermochemical cycles)
	4	Photo-catalysis (PEC) (Photo-electrochemical cell)
	9a	Electrohydrogenesis (biocatalysed electrolysis)
SUN-LIGHT	7	Photo-biological water splitting including algae bioreactors

PATHWAY SELECTION

TRL & Costs



Ludwig-Bölkow-Systemtechnik GmbH, 2015

Bibliometric study EU positioning

	Technology Specialization			Number of Patents					Growth (CAGR)			
	Asia	Europe	North America	Asia	Europe	North America	Other Regions	Total	Asia	Europe	North America	Total
1-Biomass gasification	●	●	●	190	95	77	9	371	13%	2%	5%	8%
2-Biogas reforming	✗	✓	✗	29	34	12	4	79	8%	28%	31%	23%
3-Thermochemical water splitting	●	✗	✓	90	38	48	8	184	12%	-11%	18%	8%
4-Photo-catalysis	✓	✗	✓	70	13	31	3	117	17%	0%	4%	8%
5-Fermentation	✓	✗	✗	178	12	18	1	209	9%	0%	0%	7%
7-Photo-biological water splitting	✓	✗	✗	44	11	13	0	68	6%			
6-Supercritical water gasif. of biomass	✓	✗	✗	16	5	2	0	23	-100%	-33%	0%	0%
8-Photofermentation	✓	✓	✗	30	14	3	0	47	-3%	-9%		-5%
9a-Electrohydrogenes.	✓	✗	✓	16	3	10	0	29	-9%		-9%	0%
9b-Plasma-supported gasification	✓	✗	✗	45	1	10	3	59		-100%	-100%	3%
10-Plasma-based carbon-black process	✓	✗	✗	4	0	0	1	5	-100%	0%	0%	-100%

Pathways selected from the bibliometric research

insufficient statistics

Selected on basis of KPI and bibliometric analysis

Selected on basis of bibliometric analysis

Selected on basis of bibliometric analysis

PATHWAY SELECTION

Selected pathways

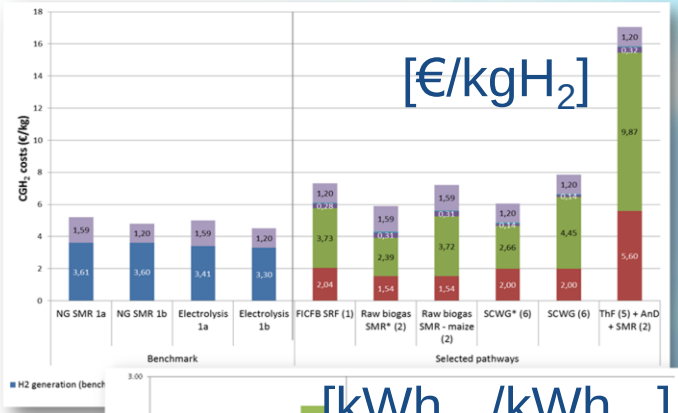
- Biomass gasification/pyrolysis
- Raw biogas reforming
- Thermochemical water splitting
- Photo-catalysis (PEC)
- Supercritical water gasification of biomass
- Combined dark fermentation and anaerobic digestion with downstream

BIOMASS	1	Biomass gasification or pyrolysis
	6	Supercritical water gasification of biomass
	2	Raw biogas reforming
	9b	Plasma-supported gasification
	10	Plasma-based carbon black process
	5	Fermentation (biological H_2 production, dark fermentation)
	8	Photofermentation (biological H_2 production)
SOLAR THERMAL	3	Thermochemical water splitting (thermochemical cycles)
	4	Photo-catalysis (PEC) (Photo-electrochemical cell)
	9a	Electrohydrogenesis (biocatalysed electrolysis)
SUN-LIGHT	7	Photo-biological water splitting including algae bioreactors

ANALYSIS OF SELECTED PATHWAYS

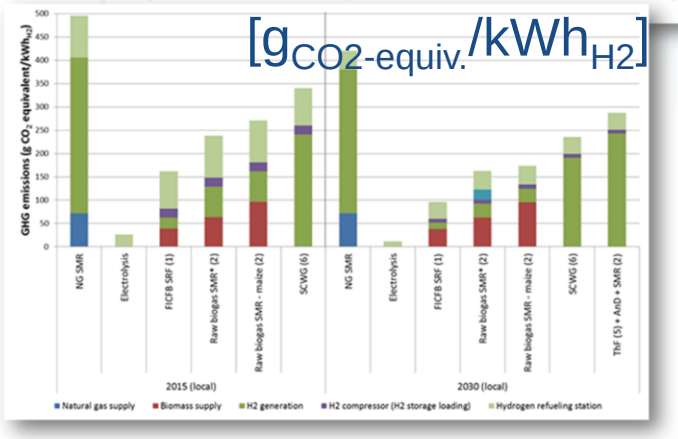
- Time horizon 2015–2030
- Assessment by applicability
- Benchmark: WEL /SMR
- Key parameters:
  - TRL on path to commercialisation
  - WtH_2 production costs
  - WtH_2 primary energy use
  - WtH_2 GHG emissions
  - Feedstock availability
  - Land use

Costs



Energy use

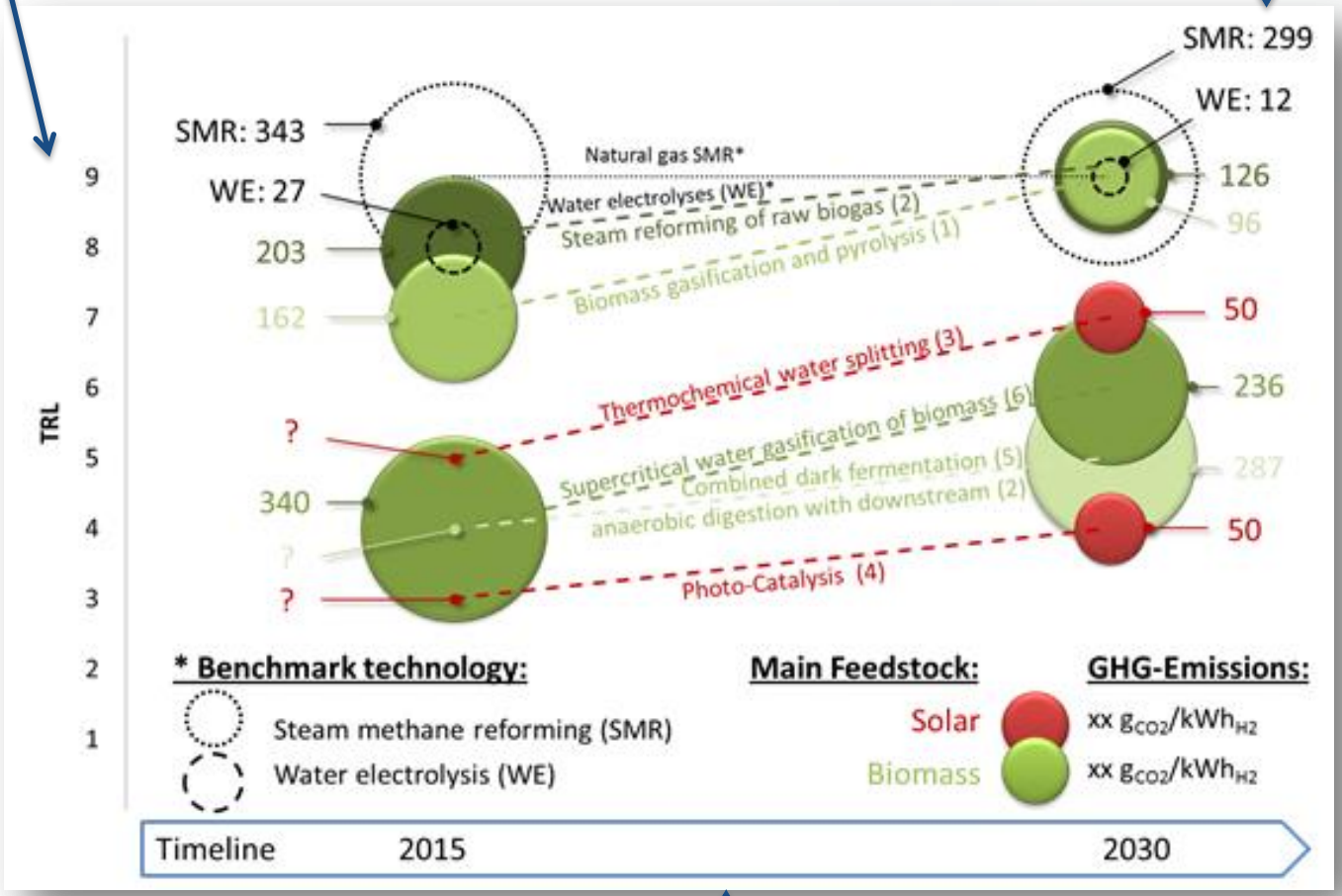
THG emissions



DEVELOPMENT ROADMAP 2015–2030

TRL

g_{CO2}/kWh_{H2}



- Raw biomass reforming
- Biomass gasification
- Thermo-chemical cycles
- Supercritical water gasification
- Fermentation
- PEC

TRL
Feedstock
GHG-emissions

Timeline 2015-2030

CONTENT PROPOSAL FOR FCH JU CALL TOPICS

- Specific challenges
  - List of the pathway specific challenges
- Scope
  - Specific challenges to be addressed in priority
  - Type of action
  - Activities to be carried out for addressing the specific challenges
- Impact
  - Performance target to be achieved through proposed actions

IDENTIFICATION OF CHALLENGES - METHODOLOGY

- For each H_2 production pathway, selection of the technologies (with TRL of at least 3) having the greatest potential of being used in 2030 (outcome of Task 3)

- For each technology:
  - Considering technical issues that may impact viability and competitiveness,

H_2 yield	Thermal efficiency	Plant capacity	Plant lifetime	Maintenance requirements	System integration
Reaction rate	Rare materials	Plant footprint	Feedstock flexibility	Operating flexibility	

  - Selection of most relevant technical issues and identification of associated most relevant specific challenges

ACKNOWLEDGEMENT

- The project team from LBST and Hinicio would like to express its gratitude to the FCH JU for placing the order with us.
- We would specifically also thank the Steering Group members from FCH JU, the European Commission and the representatives from industry and research for guiding our efforts and motivating our work.
- Finally, we highly valuate the feedback and cooperation from many experts in the field of green hydrogen technologies.